APPENDIX F

WELL AND TOTAL DISCHARGE MEASUREMENTS

F-l. General. The simplest method for determining the flow from a pump is to measure the volume of the discharge during a known period of time by collecting the water in a container of known size. However, this method is practical only for pumps of small capacity; other techniques must be used to measure larger flows.

F-2. Pipe-flow measurements.

a. Venturi meter. The flow from a dewatering system can be accurately measured by means of a venturi meter installed in the discharge line. In order to obtain accurate measurements, the meter should be located about 10 pipe diameters from any elbow or fitting, and the pipe must be flowing full of water. The flow through a venturi meter can be computed from

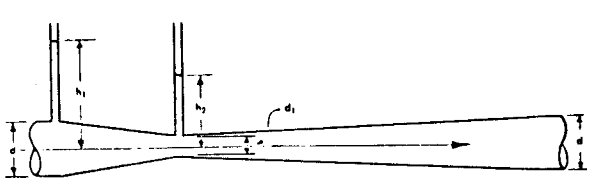
$$Q = 3.12CA = \frac{\sqrt{2g(h_1 - h_2)}}{\sqrt{1 - R^4}} \qquad \text{(F-1)}$$

where

$3.12 =$ conversion factor $= \dfrac{7.48 \text{ gal/ft}^3 \times 60 \text{ sec/min}}{144 \text{ in.}^2/\text{ft}^2}$

$Q =$ flow, gallons per minute
$C =$ calibrated coefficient of discharge (usually about 0.98)
$A =$ area of entrance section where upstream manometer connection is made, square inches
$g =$ acceleration of gravity (32.2 feet per second squared)
$h_1—h_2 =$ difference in pressure between entrance section and throat, as indicated by manometer, feet
$R =$ ratio of entrance to throat diameter $= d/d_1$

The pressures h_1 and h_2 may be taken as illustrated in figure F-l for low pressures, or by a differential mercury manometer for high pressures. Gages may be used but will be less accurate.



(Courtesy of Fairbanks Morse, Inc., Pump Division)

Figure F-l. Venturi meter.

b. Orifices.

(1) The flow from a pipe under pressure can be conveniently measured by installation of an orifice on the end of the pipe (fig. F-2), or by insertion of an orifice plate between two flanges in the pipe (fig. F-3). The pressure tap back of the orifice should be drilled at right angles to the inside of the pipe and should be perfectly smooth as illustrated in figure F-4. A rubber tube and glass or plastic pipe may be used to measure the pressure head. The diameter of the orifice plate should be accurate to 0.01 inch; the edge of the plate should be square and sharp, should have a thickness of ⅛ inch, and should be chamfered at 45 degrees as shown in figure F-2. The approach pipe must be smooth, straight, and horizontal; it must flow full, and the orifice should be located at least eight pipe diameters from any valves or fittings. The flow for various sized cap orifice-pipe combinations can be obtained from figure F-5.

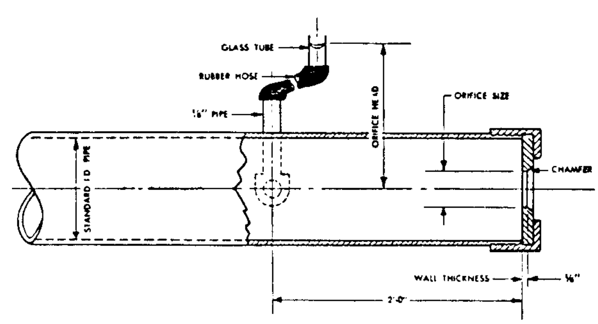
(2) The flow through an orifice in a pipe can be computed from

$$Q = CA_2 \cdot \frac{1}{\sqrt{1 - (d_2/d_1)^4}} \times \sqrt{2gh} \qquad \text{(F-2)}$$

where

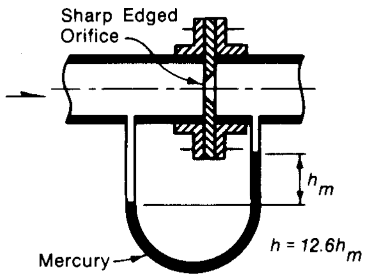
$Q =$ capacity, cubic feet per second
$C =$ orifice discharge coefficient
$A_2 =$ area of orifice, square feet
$d_2 =$ orifice diameter, inches
$d_1 =$ pipe diameter, inches
$g =$ 32.2 feet per second squared
$h =$ pressure drop across the orifice in feet of head

(3) The expression $\sqrt{1 - (d_2/d_1)^4}$ corrects for the velocity of approach. The reciprocal of this expression and the coefficient C are listed in the following tabulation for various values of d_2/d_1.



(Courtesy of Fairbanks Morse, Inc., Pump Division)

Figure F-2. Pipe cup orifice.



(Courtesy of Fairbanks Morse, Inc., Pump Division)

Figure F-3. Orifice in pipe.

d_2/d_1	C	$\frac{1}{\sqrt{1-(d_2/d_1)^4}}$
0.25	0.604	1.002
0.30	0.605	1.004
0.35	0.606	1.006
0.40	0.606	1.013
0.50	0.607	1.033
0.60	0.608	1.072
0.70	0.611	1.146
0.80	0.643	1.301
0.90	0.710	1.706

Note: The diameter of the orifice should never be larger than 80 percent of the pipe diameter in order to obtain a satisfactory pressure reading.

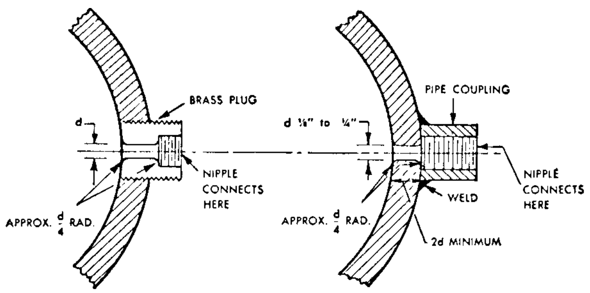
c. Pitot tube. The flow in a pipe flowing full can also be determined by measuring the velocity at different locations in the pipe with a pitot tube and differential manometer, and computing the flow. The velocity at any given point can be computed from

$$V = C\sqrt{2gh_v} \qquad \text{(F-3)}$$

where
v = velocity
C = meter coefficient
g = acceleration of gravity
h_v = velocity head

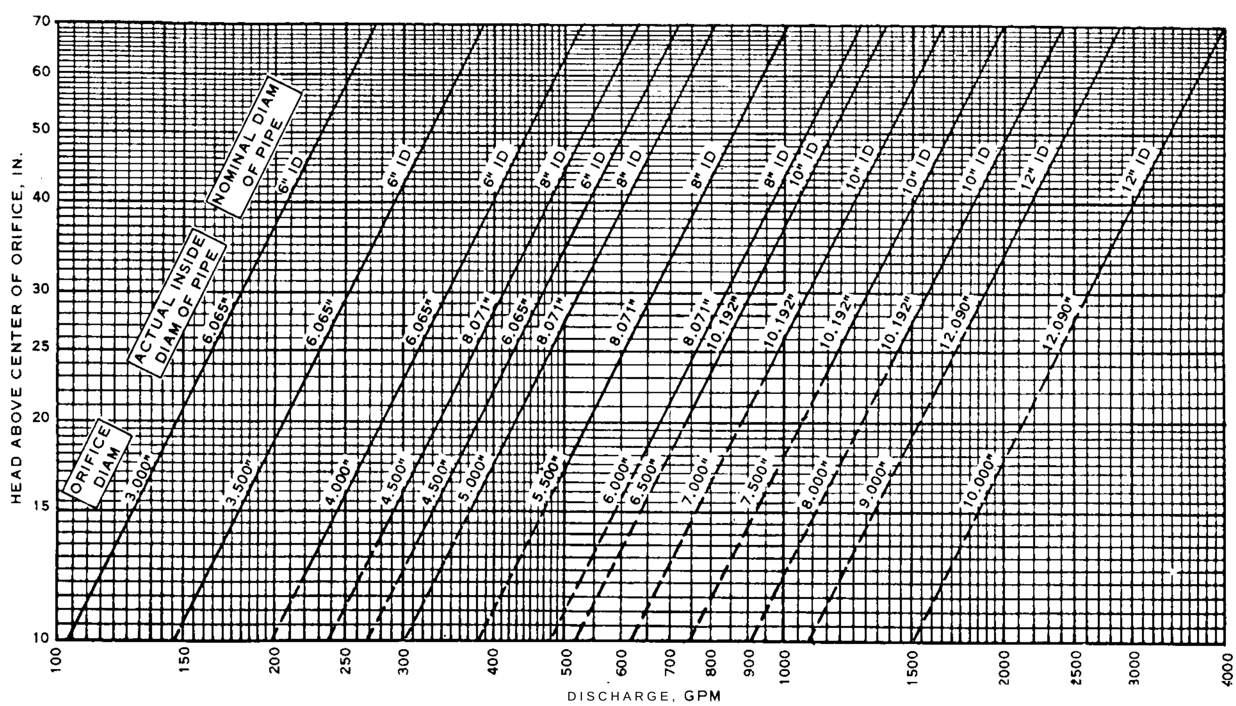
The flow is equal to the area of the pipe A times the average velocity V, or

$$Q = AV \qquad \text{(F-3a)}$$



(Courtesy of Fairbanks Morse, Inc., Pump Division)

Figure F-4. Approvedpressure taps.



(Courtesy of Fairbanks Morse, Inc., Pump Division)

Figure F-5. Pipe cap orifice chart.

where

$$V = \frac{\sum_{o}^{n} v}{n}$$

and

v = velocity at center of concentric rings of equal area

n = number of concentric rings

F-3. Approximate measurement methods.

a. Jet flow. Flow from a pipe can be determined approximately by measuring a point on the arc of the stream of water emerging from the pipe (fig. F-6), using the following equation:

$$Q = \frac{3.61Ax}{\sqrt{y}} \qquad \text{(F-4)}$$

where

Q= flow, gallons per minute

A = area of stream of water at end of pipe in square inches. If the pipe is not flowing full, the value of A is the cross-sectional area of the water jet where it emerges from the pipe. The area of the stream can be obtained by multiplying the area of the pipe times the Effective Area Factor (EAF) in figure F-7 using the ratio of the freeboard to the inside diameter of the pipe.

x = distance along axis of the discharge pipe through which the stream of water moves from the end of the pipe to a point(s), inches

y = distance perpendicular to the axis of the discharge pipe through which the stream of water drops, measured from the top or surface of the stream of water to point(s), inches

It should be noted that the x and y distances are measured from the top of the stream of water; if y is measured in the field from the top of the pipe, the pipe thickness and freeboard must be *subtracted* from the measured y to obtain the *correct* value of y.

b. Fountain flow. The flow from a vertical pipe can be approximated by measuring the height of the use of the stream of water above the top of the pipe (fig. F-8). Two types of flow must be recognized when dealing with fountain flow. At low crest heights, the discharge has the character of weir flow, while at high crest heights the discharge has the character of jet flow. Intermediate values result in erratic flow with respect to the height of the crest H.

(1) Where the flow exhibits jet character, it can be computed from

$$Q = 5.68KD^2\sqrt{H} \qquad \text{(F-5)}$$

where

Q= flow, gallons, per minute

K = constant varying from 0.87 to 0.97 for pipes 2 to 6 inches in diameter and h = 6 to 24 inches

D = inside pipe diameter, inches

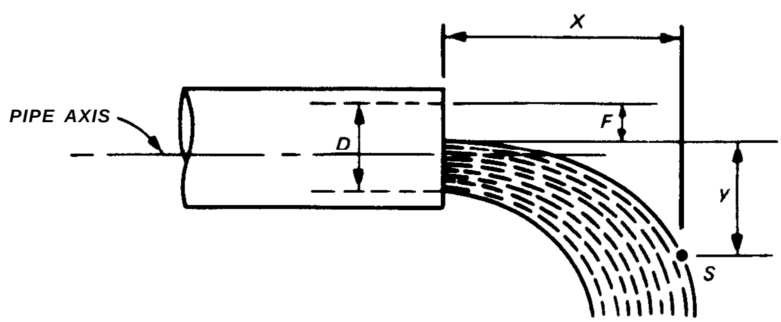
H = vertical height of water jet, inches

Where the flow exhibits weir character, it can be approximated by using the Francis Formula, $Q = 3.33 Bh^{3/2}$, with B being the circumference of the pipe.

(2) Some values of fountain flow for various nominal pipe sizes and heights of crest are given in table F-1.

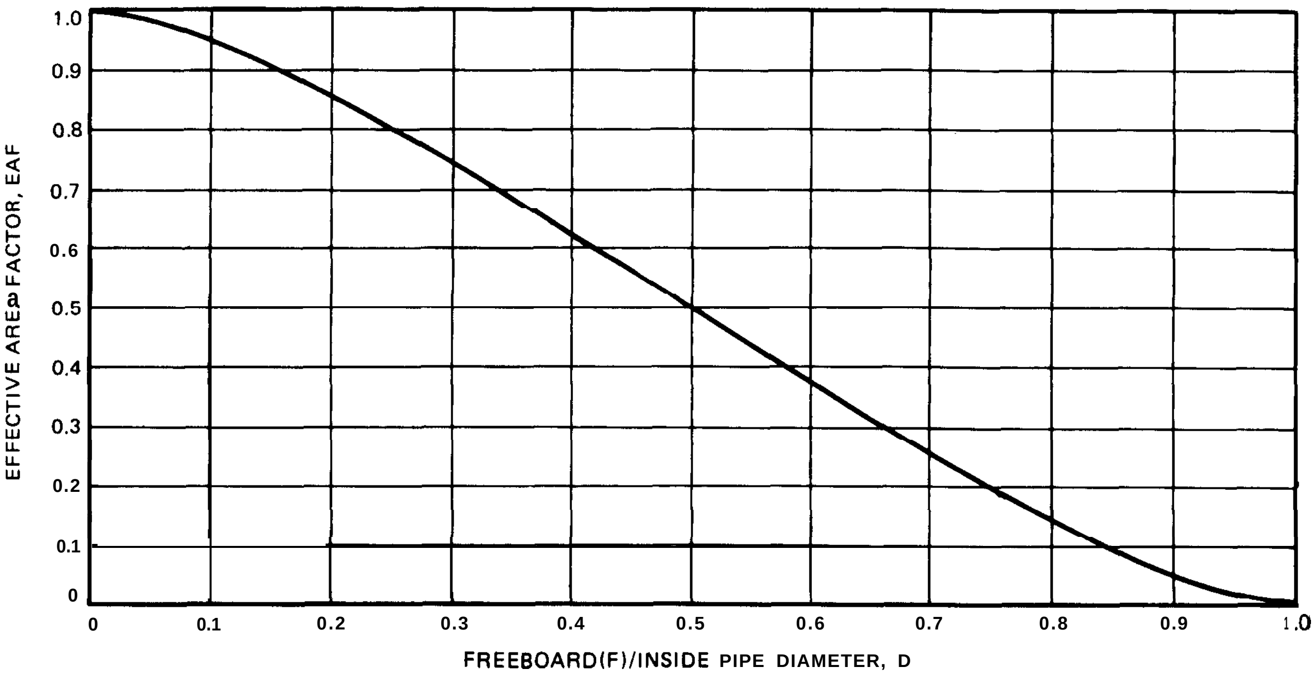
F-4. Open channel flows.

a. Weirs. Flow in open channels can be measured by weirs constructed in the channel. Certain dimensional relations should be recognized in constructing a weir to obtain the most accurate flow measurements as shown in figure F-9. The weir plate should be a noncorrosive metal about ¼ inch thick with the crest ⅛ inch wide, and the downstream portion of the plate beveled at 45 degrees, The crest should be smooth, and the plate should be mounted in a vertical plane perpendicular to the flow. The channel walls should be



U.S. Army Corps of Engineers

Figure F-6. Flow from pipe.



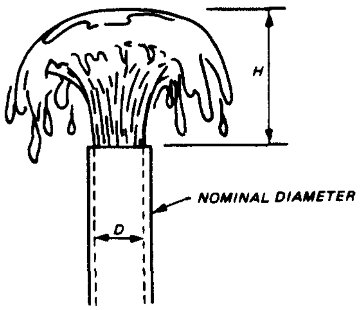
U. S. Army Corps of Engineers

Figure F-7. *Effective area factor for partially filled pipe.*

Table F-l. Flow (gallons per minute) from Vertical Pipes

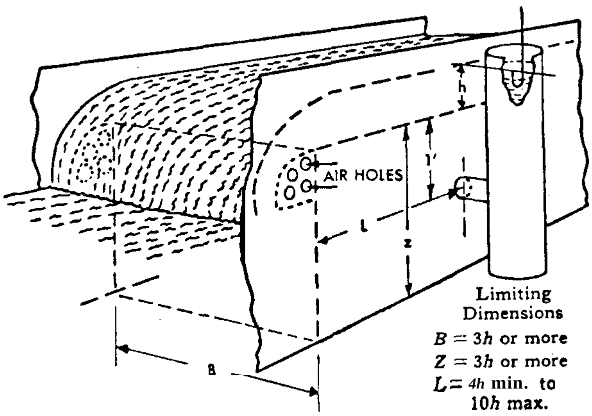
Height of Crest H inches	Nominal Diameter of Pipe, inches					
	2	3	4	5	6	8
1-1/2	22	43	68	85	110	160
2	26	55	93	120	160	230
3	33	74	130	185	250	385
4	38	88	155	230	320	520
5	44	99	175	270	380	630
6	48	110	190	300	430	730
8	56	125	225	360	510	900
10	62	140	255	400	580	1050
12	69	160	280	440	640	1150
15	78	175	315	500	700	1300
18	85	195	350	540	780	1400
21	93	210	380	595	850	1550
24	100	230	400	640	920	1650

U.S. Army Corps of Engineers



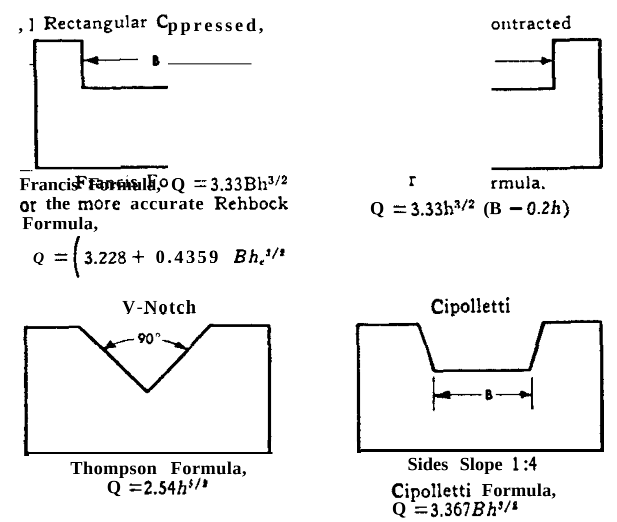
U.S. Army Corps of Engineers

Figure F-8. Fountain flow measurement.



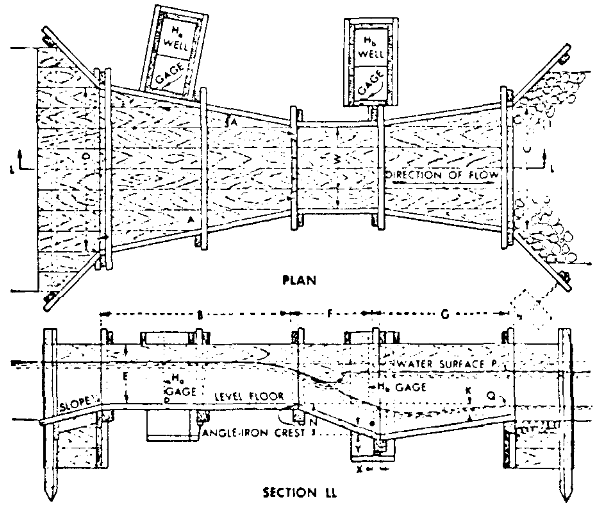
(Courtesy of Fairbanks Morse, Inc., Pump Division)

Figure F-9. Rectangular suppressed weir.



(Courtesy of Fairbanks Morse, Inc., Pump Division)

Figure F-10. Formulas for computing flow over various types of weirs.



(Courtesy of Fairbanks Morse, Inc., Pump Division)

Figure F-11. Plan and elevation of the Parshall measuring flume.

smooth and parallel, and extend throughout the region of flow associated with the weir. Complete aeration of the nappe is required for rectangular suppressed weirs. The approach channel should be of uniform section and of a length at least 15 times the maximum head on the weir. Smooth flow to and over the weir is essential to determination of accurate rates of flow. The head on the weir should be measured with a hook gage located in a stilling box at the side of the approach channel. The communication pipe to the stilling box should be about 1% inches in diameter and should be flush with the side of the channel. Formulas for calculating the flow over various types of weirs are shown in figure F-10.

b. Parshall flume. Flow in an open channel may also be measured with a Parshall flume (fig. F-11). The head drop through the flume is measured by two gates (fig. F-11); but if the depth of water at the lower gage is less than 70 percent of the depth at the upper gage, the flow is termed “free” and the discharge can be determined by reading the upstream hook gage alone. The construction and dimensions of a Parshall flume are shown in figure F-11 and table F-2. The free flow discharge of a Parshall flume is given in table F-3.

Table F-2. Dimensions and Capacities, Parshall Flumes.

Throat Width	A	⅔ A	B	C	D	E	F	G	K	N	X	Y	Free Flow Cu.ft./Sec. Max.	Min.
0'3"	1'6⅜"	1'0¼"	1'6"	0'7"	0'10 3/16"	1'4"	½'	1'	1"	2¼"	1"	1½"	1.1	0.03
0'6"	2'0 7/16"	1'4 5/16"	2'0"	1'3⅝"	1'3⅝"	2'0"	1'	2'	3"	4½"	2"	3"	3.9	0.05
0'9"	2'10⅝"	1'11⅛"	2'10"	1'3"	1'10⅝"	2'6"	1'	1½'	3"	4½"	2"	3"	8.8	0.09
1'0"	4'6"	3'0"	4'4⅞"	2'0"	2'9¼"	3'0"	2'	3'	3"	9"	2"	3"	16.1	0.35
1'6"	4'9"	3'2"	4'7⅞"	2'6"	3'4⅜"	3'0"	2'	3'	3"	9"	2"	3"	24.6	0.51
2'0"	5'0"	3'4"	4'10⅞"	3'0"	3'11½"	3'0"	2'	3'	3"	9"	2"	3"	33.1	0.66
3'0"	5'6"	3'8"	5'4¾"	4'0"	5'1⅞"	3'0"	2'	3'	3"	9"	2"	3"	50.4	0.97
4'0"	6'0"	4'0"	5'10⅝"	5'0"	6'4¼"	3'0"	2'	3'	3"	9"	2"	3"	67.9	1.26
5'0"	6'6"	4'4"	6'4½"	6'0"	7'6⅝"	3'0"	2'	3'	3"	9"	2"	3"	85.6	2.22
6'0"	7'0"	4'8"	6'10⅜"	7'0"	8'9"	3'0"	2'	3'	3"	9"	2"	3"	103.5	2.63
7'0"	7'6"	5'0"	7'4¼"	8'0"	9'11⅜"	3'0"	2'	3'	3"	9"	2"	3"	121.4	4.08
8'0"	8'0"	5'4"	7'10⅛"	9'0"	11'1¾"	3'0"	2'	3'	3"	9"	2"	3"	139.5	4.62

(Courtesy of Fairbanks Morse, Inc., Pump Division)

Table F-3. Flee-flow Discharge (in cubic feet per second), Parshall Flume.

$$Q = 4\,W\,H_a^{1.522W^{0.026}}$$

Size of Flume, *W*.

Head, H_a Feet	3"	6"	9"	1'0"	1'6"	2'0"	3'0"	4'0"	5'0"	6'0"	7'0"	8'0"
0.1	.028	.05	.09	....	....	....	......	......	......	......	......	......
0.2	.082	.16	.26	.35	.51	.66	.97	1.26	......	......	......	......
0.3	.154	.31	.49	.64	.94	1.24	1.82	2.39	2.96	3.52	4.08	4.62
0.4	.241	.48	.76	.99	1.47	1.93	2.86	3.77	4.68	5.57	6.46	7.34
0.5	.339	.69	1.06	1.39	2.06	2.73	4.05	5.36	6.66	7.94	9.23	10.51
0.6	.450	.92	1.40	1.84	2.73	3.62	5.39	7.15	8.89	10.63	12.36	14.08
0.7	.571	1.17	1.78	2.33	3.46	4.60	6.86	9.11	11.36	13.59	15.82	18.04
0.8	.702	1.45	2.18	2.85	4.26	5.66	8.46	11.25	14.04	16.81	19.59	22.36
0.9	.843	1.74	2.61	3.41	5.10	6.80	10.17	13.55	16.92	20.29	23.66	27.02
1.0	.992	2.06	3.07	4.00	6.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00
1.1	......	2.40	3.55	4.62	6.95	9.27	13.93	18.60	23.26	27.94	32.62	37.30
1.2	......	2.75	4.06	5.28	7.94	10.61	15.96	21.33	26.71	32.10	37.50	42.89
1.3	......	......	4.59	5.96	8.99	12.01	18.10	24.21	30.33	36.47	42.62	48.78
1.4	......	......	5.14	6.68	10.10	13.48	20.32	27.21	34.11	41.05	47.99	54.95
1.5	......	......	......	7.41	11.20	15.00	22.64	30.34	38.06	45.82	53.59	61.40
1.6	......	......	......	8.18	12.40	16.58	25.05	33.59	42.17	50.79	59.42	68.10
1.7	......	......	......	8.97	13.60	18.21	27.55	36.96	46.43	55.95	65.48	75.08
1.8	......	......	......	9.79	14.80	19.90	30.13	40.45	50.83	61.29	71.75	82.29
1.9	......	......	......	10.62	16.10	21.63	32.79	44.05	55.39	66.81	78.24	89.76
2.0	......	......	......	11.49	17.40	23.43	35.53	47.77	60.08	72.50	84.94	97.48
2.1	......	......	......	12.37	18.80	25.27	38.35	51.59	64.92	78.37	91.84	105.40
2.2	......	......	......	13.28	20.20	27.15	41.25	55.52	69.90	84.41	98.94	113.60
2.3	......	......	......	14.21	21.60	29.09	44.22	59.56	75.01	90.61	106.20	122.00
2.4	......	......	......	15.16	23.00	31.09	47.27	63.69	80.25	96.97	113.70	130.70
2.5	......	......	......	16.13	24.60	33.11	50.39	67.93	85.62	103.50	121.40	139.50

NOTE: Approximate values of flow for heads other than those shown may be found by direct interpolation in the table.

(Courtesy of Fairbanks Morse, Inc., Pump Division)